Coupling Infrastructure and Interoperability Layer Extension Across All Earth System Components

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LONG-TERM GOALS

A fully coupled global (atmosphere/wave/ocean/land/ice) prediction system providing daily predications out to 10 days and weekly predictions out to 30 days. Initial operational capability is targeted for 2018. Predictions will provide environmental information to meet Navy and DoD operations and planning needs throughout the globe from undersea to the upper atmosphere and from the tropics to the poles. The system will be implemented on Navy operational computer systems, and the necessary processing infrastructure will be put in place to provide products for the Navy fleet user consumption.

OBJECTIVES

The objective of this effort is to implement a flexible multi-model coupling software infrastructure, based on the Earth System Modeling Framework (ESMF) with the National Unified Operational Prediction Capability (NUOPC) Interoperability Layer, for use in both global and regional Navy ESPC systems, and integrate each of the Navy relevant models into this system. The NUOPC Interoperability Layer (a software layer that implements portions of the NUOPC Common Model Architecture (CMA) on top of ESMF) provides generic library code with hooks for specialization together with metadata, utility methods, field dictionary and a compliance checker. Basing the implementation on the ESMF/NUOPC Layer will reduce the amount of software to maintain and significantly improve the model interoperability with other systems.

APPROACH

Implement the ESMF/NUOPC Layer into each of the Navy relevant models: NAVGEM, HYCOM, WAVEWATCH III, and CICE. Implement "data models" (for reading archived model and observational data) for each of the Navy relevant models. Implement ESMF/NUOPC based coupling

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infrastructure that integrates each of the models and a mediating (flux exchange) layer. Implement & test inter-model flux exchange between the models.

The ESMF/NUOPC based coupling infrastructure, depicted in Figure 1, will consist of Models, Connector, Mediator, and Driver components. The Model components are the actual dynamical and/or physical models of the system. The Connector components provide unidirectional connection from one component to another and execute simple data transforms (Regrid or Redist). The Mediator component provides custom coupling between multiple models. It is within the Mediator component that the inter-model flux exchange calculations are implemented. The Driver component (the harness for the Models, Mediators, and Connectors) coordinates initialization and run sequencing for all components.

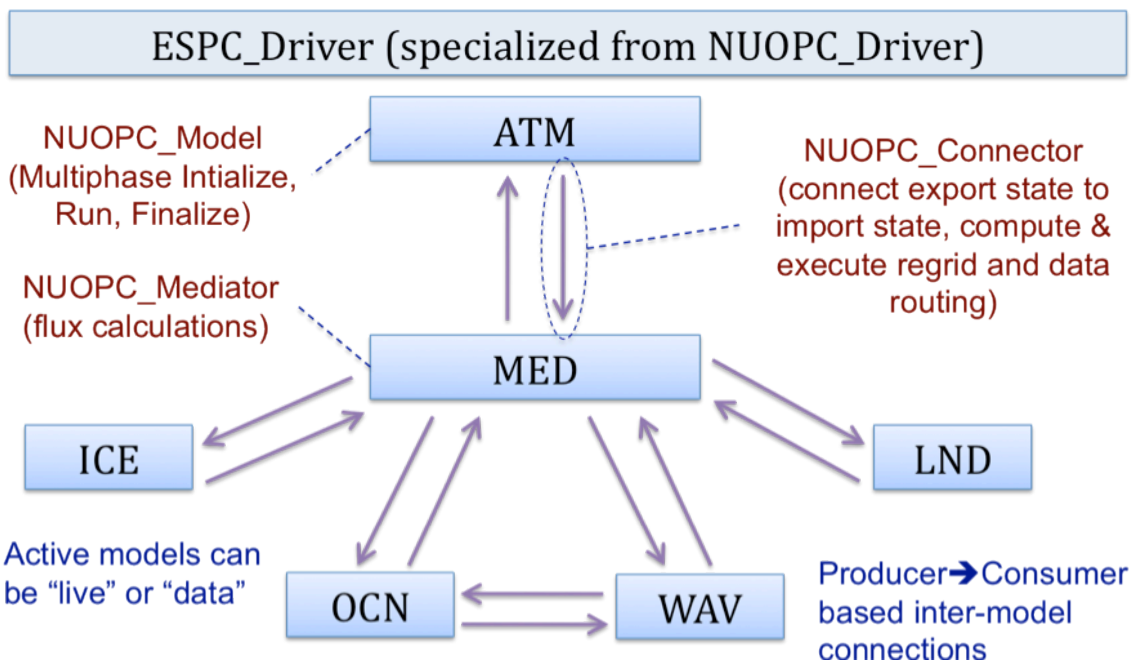

Figure 1 Schematic of software infrastructure depicting how the components specialize from the generic NUOPC components.

The required flux calculations will be implemented in the mediating layer. The models will be modified to import flux fields and export required state derived fields. The flux calculation and exchange implementations in the Mediator and Connector components will address the requirements of conservation, consistency, and flexibility. Conservation of fluxes will be addressed with conservative re-gridding and fractional cell methods. It is expected that maintaining flux consistency will require changes within each of the Models. Initial flux calculations implemented in the Mediator will be based on the algorithms currently used in the each of the models. Flexibility must be maintained to incorporate individual representations that have been previously used and extend to unified computations in the future.

WORK COMPLETED

The ESMF/NUOPC Layer, as a specialization of the NUOPC_Model, has been implemented into NAVGEM, HYCOM, and CICE. Implementation of the ESMF/NUOPC Layer into WAVEWATCH III is in progress. The implementation of this layer in each model is unique, in that it requires interfacing ESMF with the model's internal data and parallel decomposition. Mapping of the model internal data to ESMF data structures provides the means by which the model can exchange information with other models via ESMF. Data models for NAVGEM, HYCOM, and CICE have been implemented that can process archived model and observational data and function in a coupled system in the same manner as the "live" version of the model.

A flexible driver, as a specialization of the NUOPC_Driver, has been implemented that supports run-time selection of live or data versions of the models. The driver supports both concurrent and sequential mapping of models to processors. Using metadata provided by the models, the driver, via the NUOPC Layer, implements a flexible method for resolving inter-model data dependencies during the initialization sequence. Figure 2 illustrates the initialization steps for a typical atmosphere/ocean/wave coupled system in which the atmospheric initial state depends on input SST and the wave initial state depends on input wind, SSH and SSC (sea-surface currents). The ocean model initial state has no dependences and is thus computed first. After the ocean fields are communicated to the atmosphere and wave models, the atmospheric model computes its initial state. The wave model initial state is then computed after the atmospheric winds are communicated to the wave model.

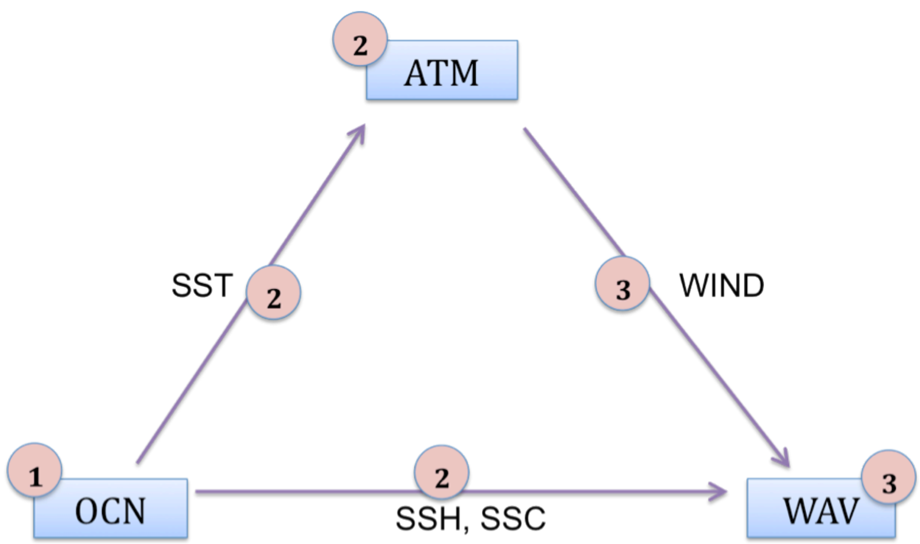

Figure 2 Graphic depicting how the initial inter-model data dependencies are resolved. Arrows indicate a data-dependency of a model that must be satisfied before the model initial state can be computed. The circled numbers indicate the order in which model initialization and connectors are executed.

Flexible sets of connectors that specialize from NUOPC_Connector have been implemented. All connectors derive from the same source code and support both bilinear and bicubic interpolation between model grids. A robust, parallel iterative extrapolation method has been implemented to handle the mismatch between model land/sea masks. The extrapolation is used to prevent, for example, using stress computed by the atmospheric model over land as a momentum flux to the ocean.

RESULTS

The developed software infrastructure has been tested with the global models in the following configurations:

1) Coupling of NAVGEM-HYCOM (Fig. 3).

This is a two-model coupled system consisting of NAVGEM coupled with HYCOM. NAVGEM provides wind stress, wind speed, surface air temperature, relative humidity, short wave and long wave radiation, and precipitation to drive HYCOM. The boundary fluxes are computed in HYCOM using a bulk formulation. HYCOM provides sea surface temperature to drive NAVGEM.

We have used the NAVGEM-HYCOM system to study the onset of an MJO that occurred on late April 2011, as observed by TRMM (Tropical Rainfall Measuring Mission), shown in Fig. 4 (left). The preliminary result indicates the MJO onset signature is reasonably captured by the coupled model (Fig. 4, right) when compared with the TRMM observation.

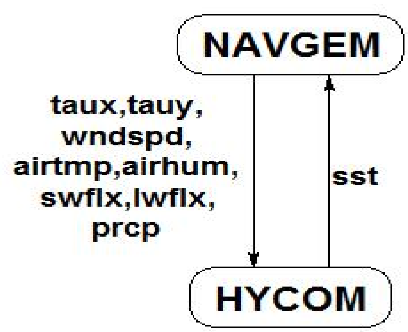

Figure 3 A system of NAVGEM coupled with HYCOM

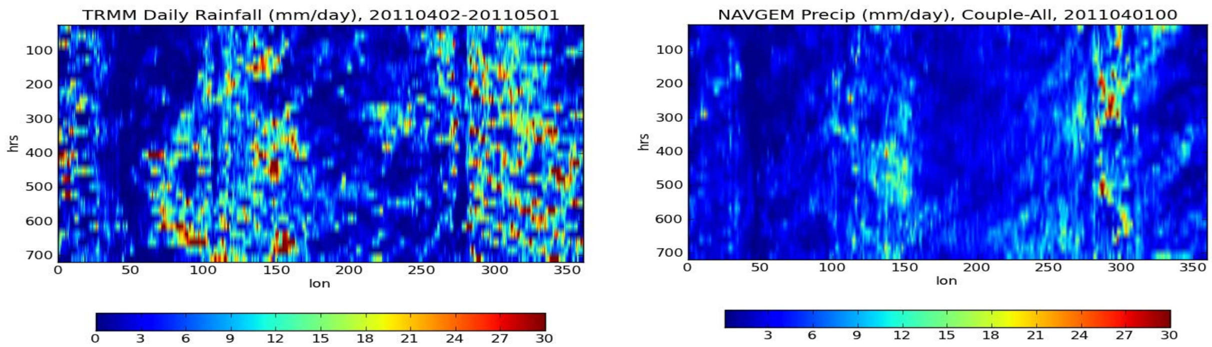

Figure 4 (left) 720 Hour (30 day) TRMM Analysis from 2 April, 2011 Rainfall Hovmoller Plots (mm/day, 5S-5N). (right) 720 Hour (30 day) NAVGEM-HYCOM Hindcasts from 2 April, 2011 Rainfall Hovmoller Plots (mm/day, 5S-5N)

2) Coupling of NAVGEM-HYCOM-CICE (Fig. 6)

This is a three-model coupled system consisting of NAVGEM, HYCOM, and CICE. NAVGEM provides wind stress, wind speed, surface air temperature, relative humidity, short wave and long wave radiation, and precipitation to drive HYCOM and CICE. HYCOM provides sea surface temperature to drive NAVGEM. HYCOM also provides sea surface temperature, salinity, and ocean surface current to drive CICE.

The development of the NAVGEM-HYCOM-CICE system is an ongoing effort. Currently, we are working to develop modules to provide coupled forcing from CICE for NAVGEM and HYCOM.

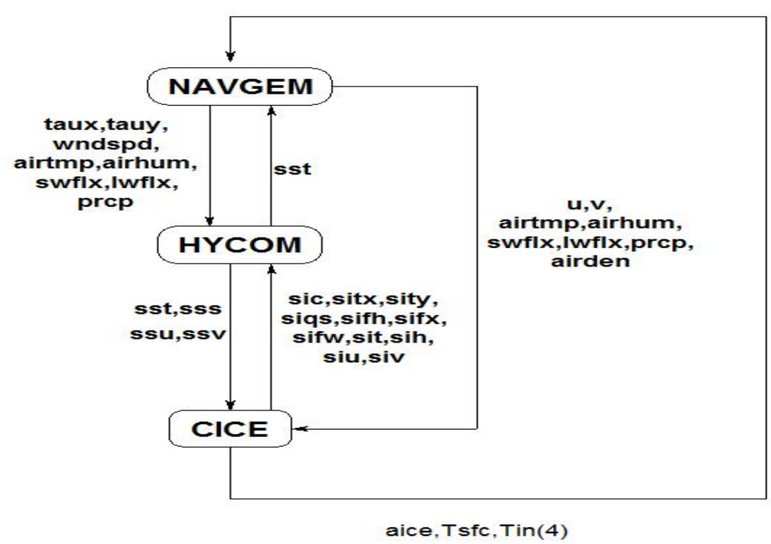

Figure 6 A system of NAVGEM coupled with HYCOM and CICE

3) Coupling of NAVGEM-Data_Ocean-CICE (Fig. 7)

This is a three-model coupled system consisting of NAVGEM, CICE, and a data ocean the processes archived HYCOM data. NAVGEM provides wind stress, wind speed, surface air temperature, relative humidity, short wave and long wave radiation, and precipitation to drive CICE. The data ocean model provides sea surface temperature to drive NAVGEM. The data ocean model also provides sea surface temperature, salinity, and ocean surface current to drive CICE. This system is useful in exploring the sensitivity of NAVGEM for improved forecasting.

The development of this system is in progress. The current effort is to develop modules to provide the coupled forcing from CICE for NAVGEM. The sea ice concentration (aice), sea ice surface temperature (Tsfc), and sea ice layer temperature (Tin) will be used to drive NAVGEM.

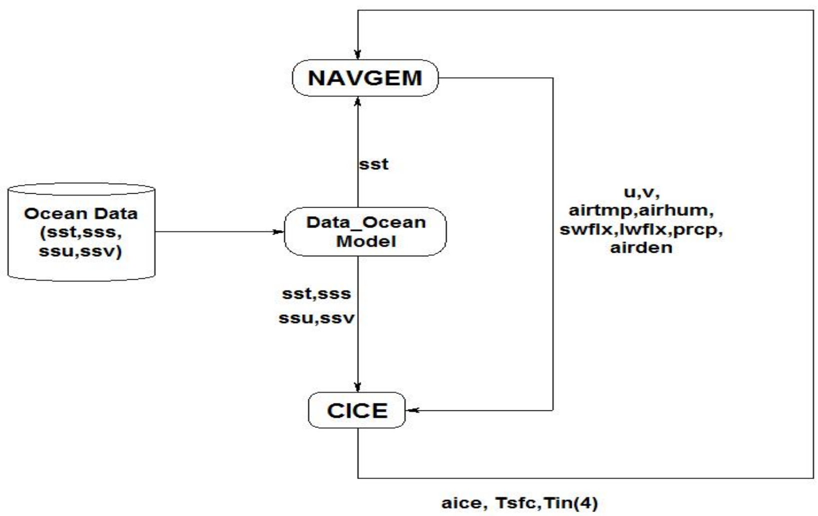

Figure 7 A system of NAVGEM coupled with Data_Ocean and CICE

IMPACT/APPLICATIONS

The software infrastructure developed under this project will be used in the next generation of Navy regional prediction capability (COAMPS) and the first generation of the Navy global prediction capability (coupled atmosphere/wave/ocean/land/ice).

TRANSITIONS

Metric testing of the coupled HYCOM / CICE / WaveWatch-III component of ESPC and complete VTR with acceptance by VTP. The VTR will document ocean model improvement associated with wave interactions and wave model improvement associated with ocean interactions. Specific metrics are still being determined.

RELATED PROJECTS

Developments in this project are coordinated with 6.2 and 6.4 projects involving COAMPS, such as, “Coupled Air-Ocean-Wave Prediction System Verification and Validation” (Rick Allard), and “A

Fully Coupled Relocatable High-Resolution Arctic Ice-Ocean-Atmosphere Modeling System" (Rick Allard).

REFERENCES

The National Unified Operational Prediction Capbility (NUOPC) Interoperability Software Layer: http://earthsystemcog.org/projects/nuopc/